1859, in spite of the smaller number of carriers, because of the more continuous high mean temperature of the summer months.

Elevation of temperature does not occur in England with the regularity and continuity necessary to maintain endemic malaria. When the necessary coincidence of carrier importation and high mean temperature occurs, both epidemic and endemic malaria may break out for a limited time in limited areas. Many other factors affect the disease, and the living conditions in England over 100 years ago may have been more favorable to its incidence, but the temperature factor is essential.

THE RATE OF ASCENT OF PILOT BALLOONS.

By Capt. B. J. SHERRY.

[Signal Corps, Washington, D. C., Dec. 14, 1920.]

The factors that control the rate of ascent of pilot balloons may be divided into two classes: (1) Those that relate to the kind and purity of the gas used, also to the shape, free lift, material and surface of the balloon, and (2) those that relate to the atmospheric conditions prevailing at the time of the ascension, with particular reference to temperature distribution and air movement. The air density, viscosity, etc., are considered only indirectly.

The factors included under the first class may be studied within doors. Dines, Hergesell, and others have made such studies. Some experiments along this same line have also been made by the Signal Corps, United States Army. The fact stands out, however, that in spite of much painstaking work by a number of investigators satisfactory information relative to the resistance encountered by large spheres in motion through air is not yet available.

The results of the experiments made by the Signal Corps indicate that, for the sizes of the balloons used, the air resistance to the motion of the balloons varies approximately as the 1.6 power of the speed and as the square of the diameter of the balloons. By making use of these results and comparing them with observations made by the two-theodolite method a formula was produced that gave the rates of ascent for pilot balloons that were in better agreement with observed results in the United States than any of the formulas heretofore used. An objectionable feature, however, to the experiments of the Signal Corps is that they were made by dropping weighted balloons instead of allowing gas-filled balloons to ascend.

Since the cube of the diameter of a balloon is proportional to its volume and, therefore, approximately proportional to its total lift, and the free lift of a balloon, ascending at a uniform rate is equal to the air resistance of the balloon, the terms "total lift" and "free lift" are used in the formulas instead of the cube of the diameter and the air resistance, respectively. Formulas for the rate of ascent of balloons are:

Signal Corps	Dines.	Rouch.	Hergesell.
$V=K\left(\frac{l}{L^{\frac{2}{3}}}\right)^{\frac{5}{8}}$	$V=K_1\frac{l^{\frac{1}{2}}}{L^{\frac{1}{3}}}$	$V=K_2\frac{l}{L^{\frac{2}{3}}}$	$V=f\left(\frac{l}{L^{\frac{2}{3}}-0.8L^{\frac{1}{3}}}\right)$

Where V is the rate of ascent; K, K_1, and K_2 are constants; 1 is the free lift, and L is the total lift of the balloons. The latest constant published for the Dines's formula is 84; for the Rouch formula 42. The value of f in the Hergesell formula is not given but a chart has been published showing the rates of ascent of balloons of various weights and free lifts. The Signal Corps, at first, adopted a value of 71 for the constant of the Signal Corps formula. This constant was, at the time, actually computed to be somewhat greater than 71. Additional observations indicate that a constant of 72 fits the data in hand somewhat better and has, therefore, been used in the latest work.

A comparison of these formulas for balloons weighing 50 grams with free lifts varying from 0 to 300 grams is shown graphically in figure 1.

It is a more difficult matter than it is ordinarily supposed to be to compare the rates of ascent as given by the formulas with the actual rates as determined in the free air by the two theodolite method.

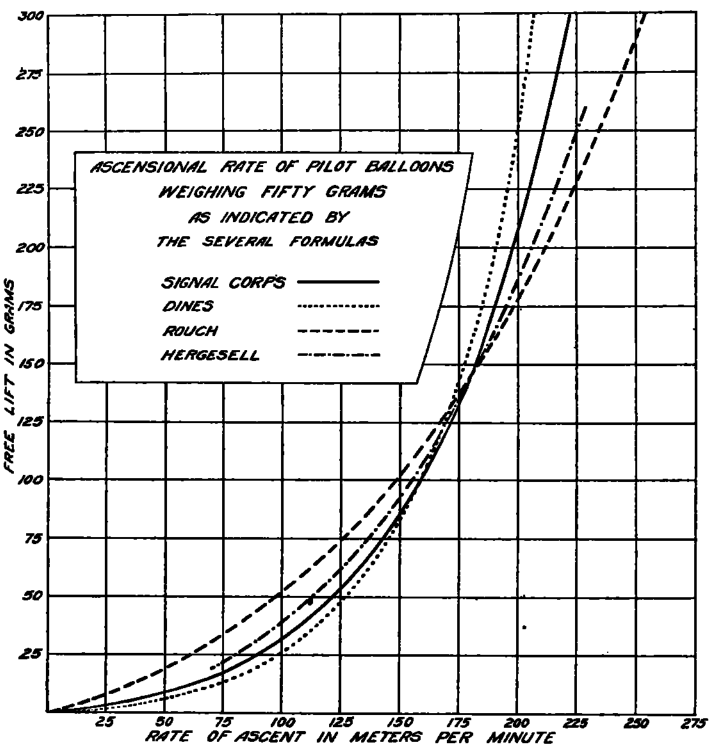

FIG 1.

Observations made in the United States indicate that the rate of ascent of a balloon may change considerably if there is a change in the shape of the balloon. It has been found that the hanging of small weights to the neck of a balloon usually increases its rate of ascent. This is probably due to the fact that balloons manufactured in the United States usually inflate to a somewhat oblong shape, the greatest diameter being through the neck of the balloon. The hanging of small weights to the neck of the balloon causes the balloon to ascend with its smallest cross section perpendicular to its direction of motion and thus with the least resistance for its size and speed. The hanging of weights to the neck of the balloon also tends to produce a streamline body and the resistance to the motion of the balloon is thus further decreased and the rate of ascent thus increased.

It was also found that the rate of ascent was further increased if the balloon was fastened into the large end of a paper cone. The balloon then ascended with the inverted cone hanging downward, thus holding the smallest cross-section area of the balloon perpendicular to its direction of motion and at the same time producing a body that was approximately streamline. It is, therefore, evident that the distortion of the shape of a balloon will affect its rate of ascent, and few balloons remain perfectly spherical during inflation or during an ascension.

The accompanying table shows how the rate of ascent of pilot balloons varies with atmospheric conditions and with the different hours of the day. The rates of ascent for 165 balloon ascensions made at various stations are considered. These ascensions were selected from about 300 made with more than ordinary care. Ascensions have not been considered where there was reason to question the accuracy of the data and all of the ascensions used were each observed for more than 10 minutes, observations of the balloon's positions being made every minute during the ascensions. The average difference of observed altitudes at the end of the periods indicated in minutes from those computed by the Signal Corps formula is given in percentage of the formula rate. This method is used because it enables one to compare more readily ascensions made with balloons differing slightly in weight and free lift. Figures preceeded by the minus sign mean that the observed rate was less and figures with plus signs before them mean that the observed rate was greater than the formula rate.

TABLE 1.—*Comparison of observed altitudes reached with computed altitudes at end of stated periods expressed in minutes.*

Atmospheric conditions.	1	2	3	4	5	10	15	20	Number of ascensions.
Strong winds (more than 10 m. p. s., all altitudes)	+32	+24	+26	+28	+27	+13	+8	.....	10
Noon to 3 p. m.	+29	+22	+21	+18	+16	+10	+7	+5	40
Winds increasing with altitude (at least 10 m. p. s. increase)	+26	+21	+21	+19	+16	+12	+8	+8	42
Clear days	+21	+17	+15	+13	+11	+8	+6	+2	23
Not more than 5 m. p. s. increase in wind speed with altitude	+25	+9	+8	+6	+6	+2	+1	+1	39
Before 9 a. m.	+22	+13	+8	+6	+5	+3	+2	+2	35
After 3.30 p. m.	+18	+12	+11	+10	+10	+7	+4	.....	18
Cloudy days (5/10 to 10/10 low clouds)	+22	+6	+8	+9	+9	+4	.....	.....	17
Wind not more than 6 m. p. s. at any altitude reached by balloons	+17	+9	+5	+2	+3	−1	−1	−1	14

It will be seen in the table that during the first five minutes of an ascension the balloons usually ascend faster than the Signal Corps formula indicates they should, regardless of the atmospheric conditions. It will also be noted that the balloons ascend faster during the prevalence of strong winds than under other conditions. The balloons ascend fast also during the part of the day when convection is strongest. Compared with all ascensions considered, the rate of ascent for the first five minutes is relatively slow on days when the wind is light.

It happens occasionally that a balloon will ascend regularly for a time and then change its rate of ascent and continue for a time at the new rate. The cause, at least in part, of these changes in rate of ascent appears to be that at points where the rate of ascent changes the balloon enters an air stream moving in a different direction or at a different speed, possibly also of different density and of a different degree of turbulence from that of the air below. The observations show clearly that a change of wind speed or direction occurs where the rate of ascent of a balloon changes.

From the data in the table, one is inclined to attribute most of the increased rate of ascent near the ground to turbulence of the air, inasmuch as days upon which the greatest air movement takes place, the balloons ascend at the greatest speed. Ascensions made when there were 5/10 to 8/10 cumulus clouds present did not show an excessive rate of ascent for the first five minutes, but on the contrary showed about the same rate as that indicated in the table for cloudy days. It is probable, however, that there is greater turbulence near the ground on clear days than on days when cumulus clouds are present. The table indicates that the effect of weather conditions, that is wind and insolation, is confined mostly to the lower levels.

An effort has been made to check the accuracy of the Signal Corps formula. It is obvious that if one uses a formula that assumes a constant rate of ascent it is impracticable to take into account the excess rate of ascent in the lower air levels. If the formula is based on the rate of ascent in relatively still air it is probable that it will agree fairly well with the rate of ascent as observed in the upper air levels, but will give rates too slow for the lower levels and consequently all the altitudes computed from such a formula under average free air conditions, will be somewhat low.

The following table shows the average difference of actual altitudes, at the end of periods indicated in minutes, from those computed by the Signal Corps formula for balloons of various free lifts. This difference is expressed in percentage of the formula rate.

TABLE 2.—*Comparison of observed altitudes reached with computed altitudes at end of stated periods expressed in minutes.*

Free lift in grams.	1	2	3	4	5	10	15	20	25	30	35	40	Number of ascensions.
20	− 9	+ 4	+ 6	+ 3	+ 3	+ 4	+ 9	.....	.....	.....	.....	.....	7
101–125	+16	+ 5	+ 5	+ 4	+ 5	+ 1	.....	.....	.....	.....	.....	.....	19
126–150	+17	+11	+10	+ 9	+ 9	+ 6	+ 1	.....	.....	.....	.....	.....	26
151–175	+ 8	− 2	+ 4	+ 5	+ 3	+ 2	+ 1	.....	.....	.....	.....	.....	9
176–200	+23	+19	+16	+13	+12	+ 6	+ 2	+ 2	0	+ 2	+ 2	.....	19
201–250	+38	+25	+20	+18	+14	+ 7	+ 7	+ 6	.....	.....	.....	.....	16
251–300	+26	+21	+18	+15	+ 9	+11	+ 6	+ 5	+ 5	+ 4	+ 2	.....	28
301–350	+31	+21	+18	+17	+14	+ 9	+ 8	+ 5	+ 3	.....	.....	.....	22
351–400	+42	+19	+12	+11	+11	+ 4	+ 2	+ 3	+ 4	.....	.....	.....	10
401–500	+11	+10	+ 9	+ 8	+ 8	+ 8	+ 3	.....	.....	.....	.....	.....	3
20–500	+23	+16	+14	+12	+10	+ 7	+ 4	+ 4	+ 2	+ 2	+ 3	+ 2	159

It is probable that no entirely satisfactory formula for the rate of ascent of pilot balloons will be produced. Near the surface of the earth the rate of apparently similar balloons will sometimes differ as much as fifty per cent and the balloons usually ascend faster than any of the formulas indicate they should. They do not appear to ascend with a uniform rate but by a series of short spurts.

After the balloons reach an altitude of approximately 1,000 meters the rates of ascent are usually much more uniform and there is better agreement in the observed rates with the rates indicated by the formulas. There is, however, so much irregularity in the behavior of the balloons in free air that it is not safe to give very much weight to any individual ascension made with one theodolite.

When great accuracy is desired observations should be made with two theodolites, if practicable, and especially is this true when the observations are confined to altitudes less than 2,000 meters above the ground. There are, however, very practical reasons why it is not always possible to use two theodolites and, therefore, a method by which observations may be made with one theodolite is necessary.

To obtain the highest degree of accuracy in pilot balloon work it is believed that a standard rate of ascent should be adopted for both one and two theodolite work. All balloons used should be as near the same weight and shape as it is practicable to obtain. They should be inflated so as to cause them to ascend at the standard rate. A balloon weighing 30 grams inflated so as to give it a free lift of 132 grams will, it is believed, be found to be a convenient combination to use. Such a balloon should ascend at the rate of approximately 183 meters (600 feet) per minute. The use of balloons of the same weight and the same free lift has the effect of eliminating some of the possible sources of error made in computing the results of the ascensions. Observers making two-theodolite observations will become familiar with the conditions that produce variations from the expected rate of ascent of the balloons and it is believed that ultimately desirable data on this problem may be collected. Increasing considerably the free lift of a balloon above 132 grams does not increase the rate of ascent sufficiently to justify the additional expense involved in securing larger balloons.

To compensate for the increase of rate in the lower levels, certain corrections may be introduced in the computations of the altitude of the balloon during the first five minutes of the ascent. It has been found that for balloon ascensions made in the United States the computed altitudes of the balloons agree best with the actual altitudes if the rate of ascent as indicated by the Signal Corps formula be increased by 20 per cent for the first minute of the ascension, 10 per cent for the second and third minutes, and 5 per cent for the fourth and fifth minutes, respectively. A long series of observations will probably indicate that an individual series of corrections should be used for each station, and, as Table 1 indicates, these corrections vary for the different hours of the day and for the different weather conditions. However, it is evident from an examination of the data in Tables 1 and 2 and it is shown also in Table 3 that the introduction of these corrections for the first five minutes of the ascension improves the accuracy of one theodolite observation.

Table 3 shows the agreement of one-theodolite observations with two-theodolite observations with and without the corrections named above.

TABLE 3.—*Number of one-theodolite observations.*

	Within 2 per cent.	Within 5 per cent.	Within 10 per cent.	Within 25 per cent.	Within 50 per cent.	In excess of 50 per cent.	Number of observations.
Without corrections	74	178	324	560	686	18	704
With corrections	92	212	389	646	700	4	704

Table 4 indicates the agreement of one-theodolite observations with two-theodolite observations and, therefore, the degree of accuracy that may be expected from one-theodolite observations.

TABLE 4.—*Showing how single-theodolite observations agree with double-theodolite observations, made at four stations.*

At end of minutes.	Within 2 per cent.	Within 5 per cent.	Within 10 per cent.	Within 25 per cent.	Within 50 per cent.	More than 50 per cent difference.	Number of observations.
1	12	30	62	118	146	4	150
2	7	36	71	136	157	4	161
3	19	39	79	144	159	4	163
4	17	44	88	140	160	2	162
5	18	49	90	145	162	1	163
10	28	68	113	152	158	0	158
15	18	54	86	105	106	0	106
20	24	42	56	62	62	0	62
25	13	30	41	46	46	0	46
30	11	22	30	30	30	0	30
35	9	15	20	20	20	0	20
40	3	4	7	8	8	0	8
Total	179	433	743	1,106	1,214	15	1,229

In preparing the above tables it was assumed that observations made with two theodolites were correct, and where the one theodolite computations gave different results it was assumed that the one theodolite method was in error. It is recognized that this assumption may be questioned. However, in several cases when three theodolites were used, altitudes computed from the three base lines were in very good agreement, usually within 4 per cent.

A number of ascensions were made with three to five balloons, each of the same free lift, tied together. The results are not conclusive, but these groups of balloons appeared to ascend at a somewhat more nearly constant rate and at about the same rate as the average rate of a number of individual balloons of the same free lift.

SOME RECENT PAPERS ON THE RATE OF ASCENT OF PILOT BALLOONS.

(Abstract and discussion.)

By W. R. GREGG.

In 1917 R. Wenger [1] advanced the theory that variations from average rates of ascent of pilot balloons are caused by turbulence of the air, this turbulence being due to various factors, including topographic irregularities, insolation effects, and marked changes in wind direction or speed as increasing altitudes are reached. As a corollary he states that the observed variations in rates of ascent can not be accepted as indicating the presence of ascending or descending currents in the atmosphere, but rather that they constitute a direct measurement of the degree of turbulence therein. This view is quite at variance with that commonly held before Wenger's paper was published.

Recently there have appeared in *Nature* two notes in which issue is taken with Wenger's conclusions. In the first [2] Van Bemmelen presents results based upon three very complete series of observations at Batavia, Bandung, and on a small coral island in the Java Sea. Insolation was very active at the first two places, but negligible at the third. The results show at the land stations a marked increase in ascent in the first kilometer during the daytime, this increase being greatest between noon and 6 p. m., and no increase whatever at night; at the small island station there was no variation either day or night. Van Bemmelen concludes, therefore, that variations are due almost entirely to vertical currents, more especially since in his observations there was rarely found a velocity as high as 15 m. p. s., above which, according to Wenger, the effects of turbulence become most pronounced. [Wenger states that a *new* turbulent state

[1] Die Steiggeschwindigkeit der Gummiballone und die Turbulenz in der Atmosphäre. Annalen der Hydrographie und Maritimen Meteorologie, 1917, 45: 121-137.

[2] High Rates of Ascent of Pilot Balloons, *Nature* (London), June 17, 1920, pp. 485-486; abstr. in *Sci. Abs.*, Dec. 30, 1920, pp. 614-615.